

Effect of various parameters on electromagnetic shielding effectiveness of textile fabrics

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The effect of material type, yarn count, pick density, type of mordant and layers of fabrics on the electromagnetic shielding properties of textile materials has been studied. The shielding effectiveness of the fabric is measured by estimating the insertion loss incurred to the signal when the sample is placed in the path of the signal at the frequency range 100 MHz-3 GHz inside the coaxial transmission holder. There are some effects of type of material, yarn count, number of fabric layers and type of mordant on electromagnetic shielding effectiveness. But the number of apertures and thread density do not have significant effect on electromagnetic shielding effectiveness, particularly in case of metallic sheets.

Keywords: Cotton, Electromagnetic shielding, Fabric, Mordant, Pick density, Polyester, Yarn count

1 Introduction

Recently, the usage of electrical and electronic devices has grown rapidly. Many devices such as AC motors, digital computers, calculators, point-of-sale terminals, printers, modems, electronic typewriters, digital circuitry, transmission line, electronic home appliances and cellular phones are capable of emitting electromagnetic waves that will result in some electromagnetic interference (EMI) problems. Electromagnetic shielding (EMS) is a process by which a material is able to reduce the transmission of electromagnetic radiation that affects the humans/equipments. An EM wave consists of an electric component and a magnetic component perpendicular to each other and propagates at right angles to the plane containing the two components. As the wave impedance is different for magnetic fields (low impedance) and electric fields (high impedance), the barrier reflection follows a different characteristic for each wave type. Electrically conductive materials such as metals reflect EM fields to prevent them from escaping or penetrating the shield. Absorption in an EM shield transforms EM energy into thermal energy. EM shields made of EM absorbers attenuate undesirable EM waves and

substantially solve EMI. The need for shielding is because we do not want frequency sources to propagate their radiation to the unwanted places. To prevent this, an enclosure must be put around the radiating device. Electromagnetic interference can take place at both close distances (near field) and far away distances (far field) and their characterizations are different. The electric and magnetic fields at the point of incidence are generally changed in magnitude and direction in the presence of the shell. An electric shielding effectiveness (S_E) and a magnetic shielding effectiveness (S_M) are defined as

$$S_E = 20 \log \left(\frac{E_i}{E_t} \right) \quad \dots (1)$$

$$S_M = 20 \log \left(\frac{B_i}{B_t} \right) \quad \dots (2)$$

where i and t refer to the incident and transmitted wave bands respectively; E , the electrical power component; and B , the magnetic power component. Shielding effectiveness can also be expressed in terms of attenuation of power. Hence, if P represents the power, then the shielding effectiveness (S) is defined as

$$S = 10 \log \left(\frac{P_i}{P_t} \right) \quad \dots (3)$$

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Shielding effectiveness is thus defined as the ratio between the field strength at a given distance from the source without the shield imposed and the field strength with the shield imposed. The total shielding effectiveness (SE) of a conductive barrier in decibel (dB) is the sum of the reflection losses (R), the absorption loss (A), and the re-reflection loss (R_r). Thus, SE is given by the following relationship:

$$SE = R + A + R_r \quad \dots (4)$$

where R , A , R_r are expressed in dB.

There is an ongoing controversy worldwide about the potential health hazards (e.g. cancer) associated with the exposure to electromagnetic fields^{1,2}. Many studies³⁻⁹ have been reported on various aspects of electromagnetic shielding effectiveness of textiles. Radiation from electric and magnetic sources has become an endemic problem today both due to the health hazards and the damage it causes in the working of electromagnetic equipment. Therefore, a need is felt to develop textile products that lead to electromagnetic shielding. The objective of the present research is to understand the effect of various parameters on electromagnetic shielding effectiveness (EMSE) of textile fabrics. The present paper deals with the effect of type of material, yarn count, pick density, type of mordant and number of layers of fabrics on electromagnetic shielding effectiveness of textile fabrics.

2 Materials and Methods

2.1 Measurement of EMSE

The evaluation of electromagnetic shielding effectiveness of textile fabrics was carried out using Agilent E5061A/E5062A ENA series RF network analyzer. A coaxial transmission holder was designed and fabricated, as per the ASTM D4935 standards¹⁰, for holding the fabric specimen during testing. The instrument consists of a signal generator and a signal receiver to measure various properties associated with the device under test. The schematic diagram of the instrument along with its various parts is shown in Fig. 1. The instrument is able to measure both the near field and the far field shielding effectiveness of all planar materials (mainly textile fabrics). The setup consists of a signal generator and a receiver coupled as a vector network analyzer in which the generated signal is converted into a rectangular or circular waveguide and transmission is through the fabric so that shielding can be done effectively^{11,12}. The output from the VNA is in the form of a graph showing

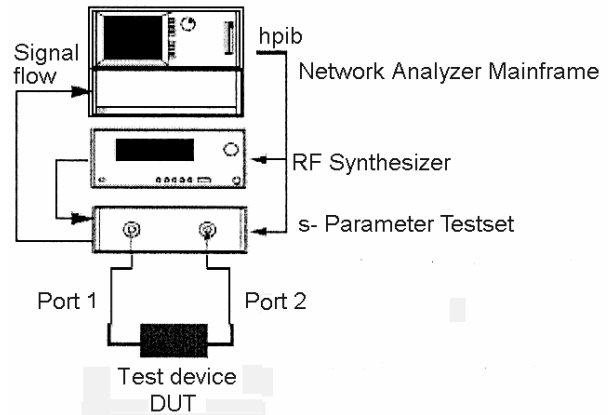


Fig. 1—Schematic diagram of network analyzer

various S-parameters, so a need is felt to convert the data from the graphical form to a quantifiable form in order to explain the behavior of the material using theoretical studies¹³. A user-friendly data acquisition system and software have been developed and interfaced between the vector network analyzer and the output to generate the required output in terms of shielding effectiveness parameters needed to calculate the electromagnetic shielding effectiveness of different fabrics. The tests were carried out to measure the electromagnetic shielding effectiveness in terms of S11 (reflected/incident) and S21 (transmitted/incident) values. The actual shielding effectiveness is only transmitted/incident values (i.e. primarily S21 values), thus in the present paper only S21 parameter has been reported.

2.2 Experimental Variables

2.2.1 Material Types

To study the effect of type of materials on the electromagnetic shielding effectiveness, different types of sheet materials, viz. paper (cellulose), copper/brass sheets (metal) and polyester (synthetic polymer), were selected. The sheet materials were selected just to simulate the planner textile fabrics. Most commonly used fibres for apparel textiles are cotton, polyester and viscose. So, paper and polyester sheets were used in the present study. The paper simulates cotton or viscose and polyester sheet simulates the 100% polyester fabrics without aperture. The metallic sheets, i.e. copper and brass, were selected as reference samples with very high shielding effectiveness. Moreover, the textile fabrics with some proportion of metal content are generally used as electromagnetic shield. To simulate the effect of mass per unit area on shielding effectiveness, three different types of papers with varying weight (Paper 1-

75.3 gsm, Paper 2- 82.6 gsm and Paper 3- 131.6 gsm) were used.

2.2.2 Number of Apertures

Textile fabrics consist of large number of apertures created by spaces between yarns. To simulate a fabric (surface with apertures), the apertures were created in the sheet materials with varying number. In the present study, the apertures (0, 5, 10, 15, 20 and 25 apertures/cm²) were made in polyester and copper sheets separately.

2.2.3 Pick Density and Yarn Fineness

To study the effect of fabric compactness on the electromagnetic shielding effectiveness, fabrics with varying pick density were prepared with same warp sheet, i.e. 2/40 Ne polyester/cotton (50/50) and 60 ends/inch. The weft yarns were of polyester/cotton (50/50) with varying picks/inch, i.e. 36, 40, 46 and 50. To study the effect of yarn fineness, 20s, 30s and 40s Ne weft yarn counts were used.

2.2.4 Layers of Fabric

To study the effect of number of fabric layers on the electromagnetic shielding effectiveness, 1, 2, 5, 10 and 20 layers of same fabrics were sandwiched before carrying out the test. The fabric used in the present set of experiment was 2/40 Ne polyester/cotton (50/50) warp with 60 ends/inch. The weft yarn was 40s Ne polyester/cotton (50/50) with 50 picks/inch.

2.2.5 Type of Metals

During the process of mordant dyeing, there is incorporation of metals on the fabric. 100% cotton sheeting fabric was used in this study. The fabric was dyed using alum, CuSO₄ and FeSO₄ to observe the effect of different metals, i.e. aluminium, copper and iron, on electromagnetic effectiveness. The metal salts were first dissolved in small amount of cold water, the amount of water was increased to 500 g, and then the fabric was immersed in the beaker. Keep the beaker at the required temperature for about 30 min. The details of recipe for application of mordants are as follows:

Salt (CuSO ₄ , Alum, FeSO ₄)	:	2% of wt. of fabric
Material-to-liquor ratio	:	1:20
Temperature	:	Room temperature (30°C) for CuSO ₄ & FeSO ₄ and 45°C for alum
Weight of fabric	:	25 g

After application of mordants, the fabrics were dyed using mordant dye. The required amount of dye was dissolved in small amount in water, then increased the amount of water to 500 cc and

immersed the fabric in the beaker for 40 min at required temperature. The dyeing conditions used are given below:

Dye	:	5% of wt. of fabric
Material-to-liquor ratio	:	1:20
Temperature	:	80°C
Fabric weight	:	25 g

3 Results and Discussion

3.1 Effect of Type of Material

Figure 2 shows the effect of type of material (i.e. cellulose, metal or synthetic polymer) on electromagnetic shielding effectiveness. The results of the experiments are found to be generally consistent with theoretical arguments, i.e. in varying material type, the following order of EMS effectiveness is observed:

Copper ≈ brass (metal) >> paper (cellulose) >
polyester (synthetic polymer)

It is evident that metals have a significantly higher EMS values compared to polymers or cellulosic material. Shielding in metals is mainly due to the reflection properties of the metal since the impedance mismatch is very high which leads to reflection of the waves. In the Fig. 2, it can be seen that there is not a marked difference in the shielding due to brass and copper, this is because the two have similar values for various parameters which affect the shielding from electromagnetic waves.

On varying the thickness or mass per unit area of the material ('paper' in the present study), it can be observed that as the thickness of paper increases (Paper 3 having maximum thickness followed by Paper 2 and least thickness of Paper 1), the EMS increases (Fig. 3). Here, it can be observed that the chart paper (Paper 3) which has the highest gsm among all is showing maximum shielding, as observed by the following equation:

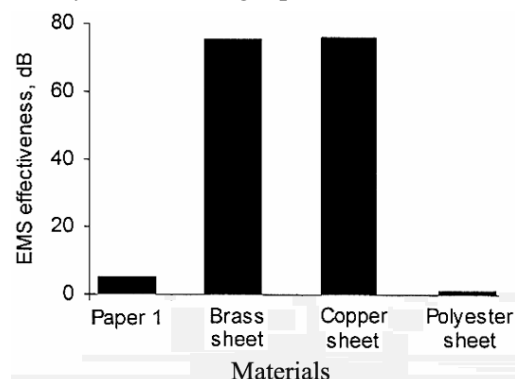


Fig. 2—Effect of types of material on EMS effectiveness

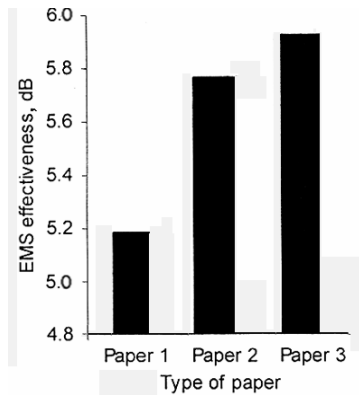


Fig. 3—Effect of thickness of material on EMS effectiveness

$$A = 1.314 \times t \sqrt{\mu_\gamma f G_\gamma} \dots (5)$$

where A is the absorption loss in dB; t , the thickness of shield in mm; f , the frequency in MHz; and μ_γ & G_γ , the constants specific to a particular material.

According to the above equation the shielding due to any material is directly proportional to the thickness of the material apart from the other parameters that are related.

3.2 Effect of Number of Apertures

Table 1 shows the effect of number of apertures on EMS effectiveness of sheet materials. For the metal, no trend is observed on increasing the number of apertures and the apertures do not seem to have any effect on the shielding provided by the metal. This may be due to the fact that the shielding due to apertures is very small compared to the overall shielding provided by the metal, and hence the small change is not evenly visible in this case. In the case of polyester sheet, the shielding seems to decrease with the increase in the number of apertures. This phenomenon can be explained by the aperture theory. In this case the thickness of the material is less than the aperture size so the shielding decreases with the increase in the number of apertures.

3.3 Effect of Yarn Count and Thread Density

Table 2 shows the effect of yarn count and picks density on EMS effectiveness of fabrics. As the yarn count reduces (i.e. yarns become coarser), the EMS effectiveness is expected to increase since a thicker fabric would mean greater absorption of the radiation. This trend is generally observed across different pick densities; however it cannot be clearly verified due to low values of EMS effectiveness. Similarly, no clear result is observed in case of total EMS effectiveness

Table 1—Effect of number of apertures on EMS effectiveness

No. of apertures/cm ²	EMS effectiveness, dB	
	Polyester sheet	Copper sheet
0	1.17	77.02
5	0.091	79.91
10	0.065	81.14
15	0.055	78.07
20	0.059	82.01
25	0.022	80.53

Table 2—Effect of yarn count and picks density on EMS effectiveness of fabrics

Pick density picks/inch	EMS effectiveness, dB		
	20s Ne	30s Ne	40s Ne
36	0.560	0.523	0.497
40	0.514	0.410	0.354
46	0.400	0.431	0.366
50	0.495	0.480	0.507

to establish whether pick density plays a major role in determining EMS effectiveness. The theory regarding the behavior of EMS effectiveness with varying pick density is also not well established due to change in both shapes of apertures with changing pick densities and size of apertures.

3.4 Effect of Number of Fabric Layers

Figure 4 shows the effect of number of fabric layers on EMS effectiveness. The results clearly show that the EMS effectiveness increases with the increase in the number of fabric layers. It is clear from Eq. (5) that as the thickness (t) increases the absorption loss (A) also increases. According to the above equation, the shielding for any material is directly proportional to the thickness of the material apart from the other parameters that are related. Hence, as the thickness of the material is increasing the shielding is also increasing. The EMS effectiveness increases with the increase in number of layers, may be due to the fact that one layer above the other can cover the apertures of the preceding layer and blocks the direct path of EM wave.

3.5 Effect of Type of Mordants

Impact of presence of different types of mordants (metals) on EMS effectiveness of different sheeting fabrics is shown in Fig. 5. The results are found to be encouraging as a clear increase in EMS effectiveness is observed across the range of mordants. It clearly shows that the mordants on the fabric cause increase in the EMS effectiveness. No clear distinction is observed to indicate which mordant is more effective. The similar effects are observed in all the three types of sheeting fabrics used in the present study. The

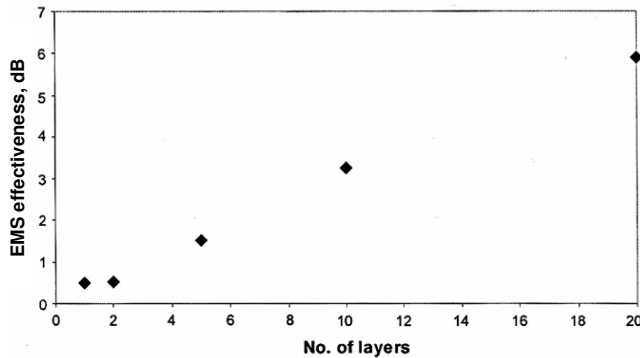


Fig. 4—Effect of number of fabric layers on EMS effectiveness

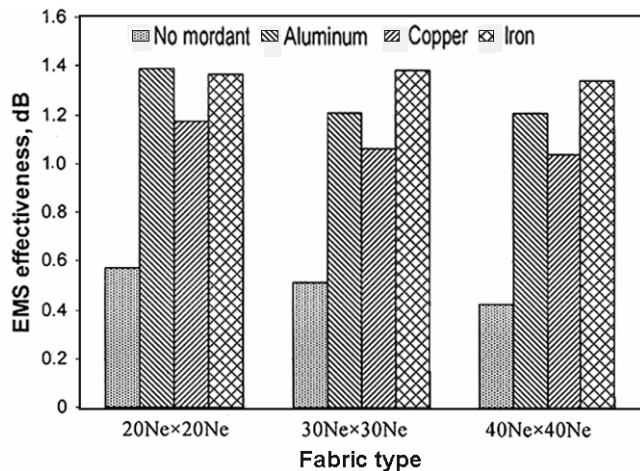


Fig. 5—Effect of application of mordants on EMS effectiveness of different sheeting fabrics

fabric made with finer yarn shows lower EMS effectiveness and the reason for this has already been explained earlier.

4 Conclusions

4.1 There are some effects of type of material, yarn count, number of fabric layers and type of mordants on electromagnetic shielding effectiveness. But the number of apertures and thread density do not have significant effect on electromagnetic shielding effectiveness, particularly in case of metallic sheets.

4.2 By varying material type, the following order of EMS effectiveness is observed: Copper \approx brass (metal) \gg paper (cellulose) $>$ polyester (synthetic polymer).

4.3 On varying the number of apertures per unit area no general trend has been observed, but in the case of polyester sheet the shielding seems to decrease with the increase in the number of apertures.

4.4 As the yarn count reduces (i.e. yarns become coarser), the EMS effectiveness increases.

4.5 EMS effectiveness also increases with the increase in the number of fabric layers.

4.6 Mordants on the fabric cause increase in the EMS effectiveness. No clear distinction is observed to indicate which mordant is more effective.

Industrial Importance: Radiation from electric and magnetic sources has become an endemic problem today both due to the health hazards and the damage it causes in the working of electromagnetic equipment. Therefore, a need is felt to develop textile products that lead to electromagnetic shielding. The present study is extremely important for those industries who are trying to produce textile fabrics for EMS application.

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